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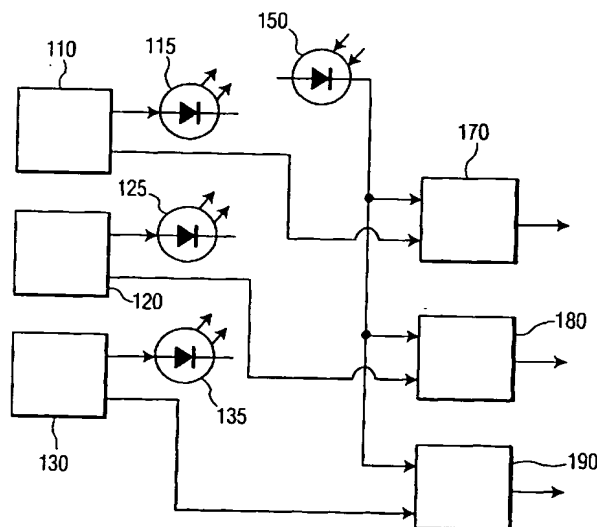
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[Continued on next page]

(54) Title: SENSING LIGHT EMITTED FROM MULTIPLE LIGHT SOURCES



(57) Abstract: An apparatus is directed to controlling a light source which provides at least one light source that emits a light signal at a discrete frequency and a reference signal at the discrete frequency. The apparatus includes a photodetector optically coupled to the light source and designed to receive the light signal. The apparatus includes at least one lock-in system coupled to the photodetector and each light source that receives the light signal from the photodetector and receives the reference signal from the light source. Each lock-in system produces an intensity value of the light source based on the light signal and the reference signal. The lock-in system may include a frequency multiplier and a filter coupled to the frequency multiplier wherein the intensity value is the product of the light signal and the reference signal processed through the frequency multiplier, and filtered to remove non-dc portions.

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SENSING LIGHT EMITTED FROM MULTIPLE LIGHT SOURCES

The technical field of this disclosure is light production from light emitting diodes (LEDs), particularly, sensing light emitted simultaneously from multiple light sources.

5 Illumination sources, such as lamps, currently utilize incandescent and fluorescent means as light production. It is well known that incandescent light sources are inefficient light sources that utilize more power resources than other light sources. Fluorescent light sources have provided a more efficient light production.

10 Light emitting diodes (LEDs) produce light in a much more efficient manner than incandescent light sources, but until recently have not been manufactured in a cost efficient manner to utilize in lighting applications. Expectations are for LEDs to produce light more efficiently than fluorescent light sources in the near future. Recently, LED production has made utilizing LEDs in light production applications a viable alternative.

15 Producing usable light with LEDs generally requires either manufacturing an LED that produces a specified color, such as utilizing a phosphor layer overlying the LED, or mixing a plurality of colored LEDs to produce a desired colored light output. Unfortunately, once a light source package is produced to achieve the desired colored light output its useful life is reduced to the amount of time until a failure or partial failure of one of its component parts occurs.

20 Unfortunately, LED characteristics depend on temperature, drive current, and time. Additionally, LED characteristics vary from LED to LED. Although an LED-based lamp may be set to operate at a given color point and intensity, at the beginning of its life, the actual color and intensity obtained at that setting may not remain constant.

25 Mixing a plurality of colored light sources may include a control system that varies individual light source contributions to correct for variation in the LED characteristics. That is, as the output of component LEDs varies, the control system can maintain a desired spectral output and intensity by varying individual LED output to compensate for the variations.

30 Currently, sensing systems for controlling a specified colored light output include temperature feed-forward or intensity feedback systems containing a single unfiltered photodiode. Another sensing system includes utilizing multiple photodiodes, for example three or more, and corresponding color filters. This system may be referred to as a color filter photodiode control system.

In one embodiment, this system can be implemented utilizing a time-based approach whereby the LEDs are pulsed on and off in a particular pattern allowing the sensing of the intensity of the independent LED groups. An advantage of the color filter photodiode control system over the temperature feed-forward or intensity feedback systems is that the color filter photodiode control system can sense the average levels of the different spectral outputs of the LEDs, for example red, green, and blue, without having to turn the LEDs on and off in a particular pattern. Additionally, a low pass filter can be used to integrate the signal from each LED group. The accuracy of this method is strongly influenced by the color filters on the photodiodes.

Unfortunately, as described above, temperature feed-forward or intensity feedback systems require that LEDs be turned on and off briefly to permit sensing of the individual color components, for example red, green and blue. This approach is susceptible to errors resulting from ripple in the driving current, and changes in the drive waveform, such as, for example changes in the rise and fall times of the LED drive current pulses. The color filter photodiode control system, although not requiring the turning on and off of LEDs to sense the individual color components, does require more expensive sensors containing color filters as well as a larger total number of sensors. None of the systems corrects for ambient light.

It would be desirable, therefore, to provide a system that would overcome these and other disadvantages.

The present invention is directed to an apparatus and method for controlling a light source. The invention provides for a frequency sensing structure that produces an intensity value input for a control system.

One aspect of the invention provides a light source control apparatus including at least one light source that emits a light signal at a discrete frequency and a reference signal at the discrete frequency. The apparatus further includes a photodetector optically coupled to the light source and designed to receive the light signal. The apparatus additionally includes at least one lock-in system coupled to the photodetector and each light source, to receive the light signal from the photodetector and an associated reference signal from the light source. Each lock-in system produces an intensity value of the light source based on the light signal and the associated reference signal.

In accordance with another aspect of the invention, the invention provides a method for sensing intensity of a light source. The method includes emitting at least one light signal where the light source is driven at a discrete frequency. The method further includes

transmitting a reference signal associated with each of the light signals at the discrete frequency. The method additionally includes producing an intensity value based on the light signal and the associated reference signal.

In accordance with yet another aspect of the invention, the invention provides a system for sensing intensity of a light source. The system includes means for emitting at least one light signal where the light source is driven at a discrete frequency. The system further includes means for transmitting a reference signal associated with each of the light signals at the discrete frequency. Means for producing an intensity value based on the light signal and the associated reference signal are also included.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

FIG. 1 is a schematic diagram illustrating a sensing device according to an embodiment of the present invention;

FIG. 2 is a schematic diagram illustrating a portion of the sensing device in **FIG. 1** according to an embodiment of the present invention;

FIG. 3 is a schematic diagram illustrating another portion of the sensing device in **FIG. 1** according to an embodiment of the present invention;

FIG. 4 is a schematic diagram illustrating a sensing device according to another embodiment of the present invention; and

FIG. 5 is a flow diagram depicting an exemplary method in accordance with the present invention.

Throughout the specification, and in the claims, the term “connected” means a direct physical or optical connection between the things that are connected, without any intermediate devices. The term “coupled” means either a direct physical or optical connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term “circuit” means either a single component or a multiplicity of components, either active or passive, that are coupled together to perform a desired function.

FIG. 1 is a schematic diagram illustrating a sensing device **100** according to an embodiment of the present invention. Device structure **100** includes control units (**110**, **120**,

and 130), light emitting diodes (115, 125 and 135), a photodetector 150, and lock-in systems (170, 180, and 190). In one embodiment, implementation of the present invention allows any number of light emitting diodes (LEDs) to be utilized, so long as there is a corresponding control unit and lock-in system for each LED. In another embodiment, each LED represents
5 a block of independently-driven LEDs with a substantially similar spectral light output. For example, LED 115 may consist of several LEDs, all emitting a red light output. Similarly, LED 125 may include all green light emitting LEDs, and LED 135 may include all blue light emitting LEDs.

In one example, the present invention is implemented as a single LED or a single
10 color group of LEDs, a single control unit, and a single lock-in unit in addition to the photodetector. In another example and referring to FIG. 1, sensing device 100 is implemented as a plurality of LEDs or multi-color LED groups, each independently-driven LED or LED group having an associated control unit and an associated lock-in system. In this example, emitted spectra of the LEDs form a multi-source light signal. For example, a
15 red, a green, and a blue LED or groups of LEDs are utilized to produce a "white" multi-source light signal.

Each control unit (110, 120, and 130), detailed in FIG. 2 below, includes an associated output drive signal terminal (Drv1, Drv2, and Drv3) and an associated output reference terminal (Ref1, Ref2, and Ref3). Each output drive signal terminal (Drv1, Drv2,
20 and Drv3) is coupled to an associated light emitting diode (115, 125 and 135).

In an example, output drive signal terminal (Drv1) is coupled to light emitting diodes (115), output drive signal terminal (Drv2) is coupled to light emitting diode (125), and output drive signal terminal (Drv3) is coupled to light emitting diode (135).

Light emitting devices (115, 125 and 135) are optoelectronic devices that produce
25 light when power is supplied causing them to forward bias. The light produced may be within the blue, green, red, amber or other portion of the spectrum, depending on the material utilized in manufacturing the LED. In an example, LEDs (115, 125 and 135) are implemented as LXHL-BM01, LXHL-BB01 and LXHL-BD01 available from Lumileds corporation of San Jose, CA. In another example, LEDs (115, 125 and 135) are implemented
30 as NSPB300A, NSPG300A and NSPR800AS from Nichia corporation of Mountville, PA.

Each control unit produces a drive signal and a reference signal, as detailed in FIG. 2 below. Power, in the form of the drive signal, is transmitted to the associated light emitting diode (LED) or LED group and the reference signal is transmitted to the associated lock-in

unit. The LED receives the drive signal and produces a light signal based on the drive signal. The drive signal is generated at a discrete frequency.

The reference signal is transmitted to the associated lock-in system and includes the same discrete frequency. Multiple control units and associated LEDs produce a light signal including several intensity values representing the intensity of light emitted by each LED or LED group.

It is important to differentiate between the discrete frequency driving the light signal emitting from each LED or LED group and the very high frequency that the LED or LED group emit as light. Typically, as described below, the drive signals range from about 400 Hz to about 1.2 kHz while the light emitted from the LEDs or LED groups is in the order of 10^{14} Hz.

Photodetector 150 is an optoelectronic device that responds to light signals and produces a received light signal. In one embodiment, photodetector 150 is implemented as a photodiode, such as, for example PS 1-2CH from Pacific Silicon Sensor, Inc of Westlake Village, CA. Photodetector 150 includes an output signal terminal (Rec) for supplying the received light signal.

In one embodiment, photodetector 150 responds to a single source light signal and produces a received light signal, at the output signal terminal (Rec), which corresponds to the intensity of light produced by that single light source. In another embodiment and described in FIG. 5 below, photodetector 150 responds to the multi-source light signal and produces a received light signal, at the output signal terminal (Rec). The received light signal includes components at multiple frequencies, each component corresponding to the intensity of one light source in the multi-source light signal.

Each lock-in system (170, 180, and 190) includes a lock-in device, detailed in FIG. 3 below. Each lock-in system (170, 180, and 190) further includes an input signal terminal (Rec) and an associated input reference terminal (Ref1, Ref2, and Ref3). Each input signal terminal (Rec) of each associated lock-in system (170, 180, and 190) is coupled to the output signal terminal (Rec) of photodetector 150. Each input reference terminal (Ref1, Ref2, and Ref3) of each associated lock-in system (170, 180, and 190) is coupled to the output reference terminal (Ref1, Ref2, and Ref3) of each associated control unit (110, 120, and 130).

In an example, output reference terminal (Ref1) of control unit 110 is coupled to input reference terminal (Ref1) of lock-in system 170, output reference terminal (Ref2) of control unit 120 is coupled to input reference terminal (Ref1) of lock-in system 180, and output

reference terminal (Ref3) of control unit 130 is coupled to input reference terminal (Ref3) of lock-in system 190.

Each lock-in system (170, 180, and 190) further includes an associated output intensity signal terminal (Int1, Int2, and Int3), detailed in FIG. 3 below. Each lock-in system receives an input signal, at the input signal terminal (Rec), from photodetector 150 and a reference signal, at the input reference terminal (Ref1, Ref2, and Ref3), from an associated control unit (110, 120, and 130). Each lock-in system produces an output intensity signal, at the associated output intensity signal terminal (Int1, Int2, and Int3), based on the received input signal and reference signal.

In a further embodiment, sensing device 100 includes a high-pass filter coupled between the output reference terminal (Ref1, Ref2, and Ref3) of each control unit (110, 120, and 130) and the input reference terminal (Ref1, Ref2, and Ref3) of the associated lock-in system (170, 180, and 190). In one embodiment, coupling a high-pass filter between the control unit and the lock-in system reduces spurious dc components from affecting the reference signal.

FIG. 2 is a schematic diagram illustrating a control unit 210 according to an embodiment of the present invention. Control unit 210 includes a frequency shifter 215, a power distributor 217, an input clock signal terminal (Clk), an input power signal terminal (Pwr), an output reference signal terminal (Ref), and an output drive signal terminal. Control unit 210 receives a clock signal and a power signal, produces a reference signal based on the clock signal, and produces a drive signal based on the reference signal and the power signal.

Frequency shifter 215 includes an input clock signal terminal (Clk) and an output reference signal terminal (Ref). Frequency shifter 215 receives the clock signal and produces the reference signal based on the clock signal. In one embodiment, frequency shifter 215 receives the clock signal and “divides down” the clock signal to produce the reference signal. The reference signal frequency utilized is produced at a frequency so as not to cause noticeable “flicker” to the human eye. In an example, a reference signal is produced in the 100 Hz – 2.4 kHz range.

In another embodiment, frequency shifter 215 includes an internal clock that generates the clock signal internally thereby eliminating the need for the clock terminal (Clk).

Additionally and referring to FIG. 1, the use of multiple control units (110, 120, and 130) requires several discrete frequencies. The frequencies utilized are produced so that frequency overlap will not occur. In one embodiment, the frequencies utilized are produced

with a 100 Hz gap between discrete frequencies. In an example, control unit 110 produces a reference frequency at 400 Hz, control unit 120 produces a reference frequency at 500 Hz, and control unit 130 produces a reference frequency at 600 Hz.

Power distributor 217 includes an input power terminal (Pwr), an input reference
5 signal terminal (Ref), and an output drive signal terminal (Drv). The input reference terminal (Ref) of power distributor 217 is coupled to the output reference terminal (Ref) of frequency shifter 215. Power distributor 217 receives the power signal and the reference signal and produces the drive signal based on the power signal and the reference signal.

In one embodiment, the power signal is implemented as a voltage source signal. In
10 another embodiment, the power signal is implemented as a current source signal. In an example, power distributor 217 produces a drive signal including a current signal modulated at a discrete frequency associated with the reference signal.

The power signal may be produced in the form of one of several different waveforms,
such as, for example, a sine wave, a cosine wave, a square wave, or any other waveform that
15 would allow the production of the light signal.

FIG. 3 is a schematic diagram illustrating a lock-in device 370 according to an
embodiment of the present invention. Lock-in device 370 includes a signal multiplier 375, a
filter 377, an input signal terminal (Rec), an input reference terminal (Ref), and an output
intensity terminal (Int). Lock-in device 370 receives an input signal and a reference signal,
20 and produces an intensity signal based on the input signal and the reference signal.

Signal multiplier 375 includes an input signal terminal (Rec), an input reference
terminal (Ref), and an output product terminal (Prd). Signal multiplier 375 receives the input
signal and the reference signal, and produces a product signal based on the input signal and
the reference signal. Signal multiplier 375 produces the product signal by multiplying the
25 input signal by the reference signal, detailed in **FIG. 5** below. Signal multiplier 375 can be
implemented as a signal multiplier chip, such as, for example the MLT04 produced by
Analog Devices of Norwood, MA.

Filter 377 includes an input product terminal (Prd) and an output intensity terminal
(Int). The input product terminal (Prd) of filter 377 is coupled to the output product terminal
30 (Prd) of signal multiplier 375. Filter 377 receives the product signal and filters the received
product signal to remove non-dc portions of the signal. In one embodiment, filter 377 is
implemented as a low-pass filter.

FIG. 4 is a schematic diagram illustrating a sensing device **400** according to another embodiment of the present invention. Device structure **400** includes control units (**110**, **120**, and **130**), light emitting diodes (**115**, **125** and **135**), photodetectors **450** and **455**, and lock-in systems (**470**, **480**, and **490**). Like components from **FIG.1** are numbered identically and function identically. In one embodiment, implementation of the present invention allows any number of light emitting diodes (LEDs) to be utilized, so long as there is a corresponding control unit and lock-in system for each independently driven LED or group of LEDs.

Photodetectors **450** and **455** are optoelectronic devices that respond to light signals across the whole visible spectrum, and each produce a received light signal within a predetermined spectrum. In one embodiment, photodetectors **450** and **455** are implemented as two separate single junction photodiodes, such as, for example PSS 1-2CH from Pacific Silicon Sensor, Inc. In this embodiment, photodetector **450** includes an output signal terminal (Rec1) for supplying a portion of the received light signal, and photodetector **455** includes an output signal terminal (Rec2) for supplying another portion of the received light signal.

In another embodiment, photodetectors **450** and **455** are implemented as a multi-junction photodiode, such as, for example PSS-WS7.56 from Pacific Silicon Sensor, Inc. In this embodiment, photodetector **450** represents a first junction of the multi-junction photodiode, and photodetector **455** represents a second junction of the multi-junction photodiode. One junction is more sensitive to red wavelengths, and the other is more sensitive to blue wavelengths. Comparison of the measurements of the two junctions provides a measure of spectral shift.

In an example, photodetector **450** responds more strongly than photodetector **455** to light signals within the spectrum defined as greater than about 600nm. In this example, photodetector **455** responds most strongly than photodetector **450** to light signals within the spectrum defined as less than about 600nm.

Photodetectors **450** and **455** respond to single and multi-source light signals and produce a received light signal, at the output signal terminals (Rec1 and Rec2). In one embodiment, each received light signal includes single or multiple intensity values. In this embodiment, each intensity value includes a discrete frequency.

In another embodiment, each received light signal includes components at single or multiple frequencies. In this embodiment, each component corresponds to the intensity of one light source in the multi-source light signal.

Each lock-in system (470, 480, and 490) includes multiple lock-in devices (475, 477, 485, 487, 495, and 497), each lock-in device functions as described in FIG. 3 above. In one embodiment, the number of lock-in devices within each lock-in system is equal to the number of photodetectors. In an example, lock-in devices (475, 485, and 495) are coupled to photodetector 450 via input signal terminal (Rec1), and lock-in devices (477, 487, and 497) are coupled to photodetector 455 via input signal terminal (Rec2).

Each lock-in system (470, 480, and 490) further includes associated input reference terminals (Ref1, Ref2, and Ref3). Input reference terminals (Ref1, Ref2, and Ref3) of each associated lock-in system (470, 480, and 490) are coupled to the output reference terminal (Ref1, Ref2, and Ref3) of each associated control unit (110, 120, and 130). In an example, output reference terminal (Ref1) of control unit 110 is coupled to each input reference terminal (Ref1) of lock-in devices (475 and 477) within lock-in system 470. Output reference terminal (Ref2) of control unit 120 is coupled to input reference terminal (Ref1) of lock-in devices (485 and 487) within lock-in system 480. Output reference terminal (Ref3) of control unit 130 is coupled to input reference terminal (Ref3) of lock-in devices (495 and 497) within lock-in system 490.

Each lock-in device (475, 477, 485, 487, 495, and 497) further includes multiple output intensity signal terminals (Int1/1, Int2/1, Int1/2, Int2/2, Int1/3, and Int2/3). In one embodiment, the number of output intensity signal terminals within each lock-in system is equal to the number of lock-in devices, and therefore is equal to the number of photodetectors.

Each lock-in device receives a portion of the received light signal from an associated photodetector, and receives a reference signal from an associated control unit. Each lock-in system produces an output intensity signal, at the associated output intensity signal terminal (Int1/1, Int2/1, Int1/2, Int2/2, Int1/3, and Int2/3), based on the received input signal and reference signal.

In a further embodiment, sensing device 100 includes a high-pass filter coupled between the output reference terminal (Ref1, Ref2, and Ref3) of each control unit (110, 120, and 130) and the input reference terminal (Ref1, Ref2, and Ref3) of the associated lock-in system (470, 480, and 490). In one embodiment, coupling a high-pass filter between the control unit and the lock-in system reduces spurious dc components from affecting the reference signal.

FIG. 5 is a flow diagram depicting an exemplary method for sensing intensity of a light source in accordance with the present invention. Method **500** may utilize one or more systems detailed in **FIGS. 1–4**, above.

Method **500** begins at block **510** where a control system for a light source determines a need to sense the intensity of one or more light emitting diodes (LEDs) or groups of LEDs within the light source. Method **500** allows the control system to determine power requirements for each LED by providing the control system with an intensity value for each LED or group of independently-driven LEDs. Method **500** then advances to block **510**.

At block **510**, the light source emits a light signal. Referring to **FIGS. 1** and **2**, the light source includes at least one light emitting diode (LED) or group of LEDs, each independently-driven LED or group of LEDs emitting a light signal that includes an intensity value within the LED's spectral band, and being driven with a current waveform at a discrete frequency.

In an example, the light source includes three LEDs or groups of LEDs, each LED or group of LEDs coupled to and receiving a drive signal from an associated control unit (**110**, **120**, and **130**), and combining to produce a “white” light output. That is, LED (**115**) is driven with an AC current at a frequency ω_R and emits light in the red spectrum, LED (**125**) is driven with an AC current at a frequency ω_G and emits light in the green spectrum, and LED (**135**) is driven with an AC current at a frequency ω_B and emits light in the blue spectrum. For illustrative purposes, a cosine waveform is utilized. The resulting light signal is then expressed as:

$$A_R \cos \omega_R t + A_G \cos \omega_G t + A_B \cos \omega_B t$$

where A is the magnitude and ω is the frequency of the associated signal.

In this example control unit (**110**) and LED (**115**) produce the $A_R \cos \omega_R t$ component, control unit (**120**) and LED (**125**) produce the $A_G \cos \omega_G t$ component, and control unit (**130**) and LED (**135**) produce the $A_B \cos \omega_B t$ component. In this example and referring to **FIG. 1**, the red LED (**115**) is driven at 400 Hz (ω_R), the green LED (**125**) is driven at 500 Hz (ω_G), and the blue LED (**135**) is driven at 600 Hz (ω_B).

In one embodiment, a square wave is utilized as the waveform characteristics include the ability to set the lower portion of the waveform to zero amps. The ability to set the lower

portion of the waveform to zero is important as it allows for cancellation of undesirable components during production of an output intensity signal.

In one embodiment and referring to FIGS. 1 and 3 above, the light signal is received by photodetector 150 and transmitted to each lock-in system (170, 180, and 190) as the received light signal. In another embodiment and referring to FIGS. 3 and 4 above, the light signal is received by photodetectors 450 and 455, and transmitted to each lock-in system (470, 480, and 490) as the received light signal.

In this embodiment, a portion of the received light signal, received by photodetector 450, is transmitted to one lock-in device (475, 485, and 495) within each lock-in system (470, 480, and 490). Additionally, another portion of the signal, received by photodetector 455, is transmitted to the other lock-in device (477, 487, and 497) within each lock-in system (470, 480, and 490). Method 500 then advances to block 520.

At block 520, the control unit transmits a reference signal to an associated lock-in system. In one embodiment and referring to FIG. 1, each control unit (110, 120, and 130) transmits an associated reference signal to an associated lock-in system (170, 180, and 190). In this embodiment, each reference signal is produced by the associated control unit and transmitted at a discrete frequency.

In an example and referring to FIGS. 1 and 2, control unit 210 receives the clock signal and produces the reference signal based on the clock signal. Alternatively and detailed in FIG. 2 above, the frequency could be generated internally within each controller thereby negating the need for an external clock. Additionally, for illustrative purposes a cosine waveform is utilized. The resulting reference signal is then expressed as:

$$I_{ref} \cos \omega_{ref} t$$

where I_{ref} is the magnitude and ω_{ref} is the frequency of the reference signal.

In this example, the reference signal produced by control unit 120 is expressed as:

$$I_{ref} \cos \omega_G t$$

The reference signal is then transmitted to each lock-in system. In one embodiment, the reference signal is transmitted to each lock-in system (170, 180, and 190) as the reference signal of FIG. 1, above. In another embodiment, the reference signal is transmitted to each

lock-in system (470, 480, and 490) as the reference signal of FIG. 4, above. Method 500 then advances to block 530.

At block 530, the lock-in system produces an intensity value based on the received light signal and the associated reference signal. In one embodiment and referring to FIG. 1, each lock-in system (170, 180, and 190) receives the received light signal from photodetector 150 and receives an associated reference signal from an associated control unit (110, 120, and 130).

In an example and referring to FIGS. 1 and 3, signal multiplier 375 of lock-in device 370 receives the received light signal and the associated reference signal. In this example, signal multiplier 375 produces a product signal by multiplying the received light signal by the associated reference signal. The resulting product signal is then expressed as:

$$I_{ref} * A_R \cos \omega_{ref} t \cos \omega_R t + I_{ref} * A_G \cos \omega_G t * \cos \omega_R t + I_{ref} * A_B \cos \omega_B t * \cos \omega_R t$$

multiplication of the cosine terms results in the product signal expressed as :

$$\begin{aligned} & \frac{1}{2} I_{ref} * A_R \cos(\omega_{ref} - \omega_R) t + \frac{1}{2} I_{ref} * A_R \cos(\omega_{ref} + \omega_R) t + \frac{1}{2} I_{ref} * A_G \cos(\omega_{ref} - \omega_G) t + \\ & \frac{1}{2} I_{ref} * A_G \cos(\omega_{ref} + \omega_G) t + \frac{1}{2} I_{ref} * A_B \cos(\omega_{ref} - \omega_B) t + \frac{1}{2} I_{ref} * A_B \cos(\omega_{ref} + \omega_B) t \end{aligned}$$

In this example and described above, lock-in device 370 represents the lock-in device within lock-in system 180 of FIG. 1, above. Therefore, the resulting reference signal is produced by control unit 120 and expressed as:

$$I_{ref} \cos \omega_{ref} t = I_{ref} \cos \omega_G t$$

substitution results in the product signal expressed as:

$$\begin{aligned} & \frac{1}{2} I_{ref} * A_R \cos(\omega_G - \omega_R) t + \frac{1}{2} I_{ref} * A_R \cos(\omega_G + \omega_R) t + \frac{1}{2} I_{ref} * A_G + \frac{1}{2} I_{ref} * A_G \cos 2 \omega_G t + \\ & \frac{1}{2} I_{ref} * A_B \cos(\omega_G - \omega_B) t + \frac{1}{2} I_{ref} * A_B \cos(\omega_G + \omega_B) t \end{aligned}$$

In this example, the product signal is then transmitted to filter 377. Filter 377 is implemented as a low-pass filter having a cutoff frequency that discards the non-dc terms. The cutoff frequency must be less than either $(\omega_G - \omega_R)$ or $(\omega_G - \omega_B)$, for example, below 100

Hz when utilizing the above example frequencies. The result of filtering the product signal is removal of the non-dc terms and is expressed as:

$$\frac{1}{2}I_{\text{ref}} * A_G$$

In this example and referring to **FIGS. 1** and **3**, the resulting signal is the intensity value. The reference intensity value may be removed, for example, by “dividing” it out. Alternatively, an unaltered intensity value can be returned to the control system.

In another embodiment and referring to **FIG. 4**, each lock-in system (**470**, **480**, and **490**) receives the received light signal from photodetectors **450** and **455**, and receives an associated reference signal from an associated control unit (**110**, **120**, and **130**). In this embodiment, one lock-in device of each lock-in system, for example lock-in device **485** of lock-in system **480**, receives a portion of the received light signal. The second lock-in device of each lock-in system, for example lock-in device **487** of lock-in system **480**, receives another portion of the received light signal. Each lock-in device (**485** and **487**) produces a component intensity value at the associated intensity signal terminal (**Int1/2**, **Int2/2**), as described above. In an example, the component intensity values are summed to produce a single intensity value for the associated spectrum (e.g. Green). In an example, the ratio of the two components values provides a measure of any spectral shifts that may have occurred during light source operation. Method **500** then advances to block **550**, where it returns the intensity values to the control system.

The control system utilizes the intensity values to determine the amount of power to supply to the LEDs of the light source. In one embodiment and referring to **FIG. 1**, the control system determines power adjustment requirements by cross indexing each provided LED intensity value with a thermal value (already received). In an example, each provided LED intensity value and thermal value are cross indexed in a look-up table that includes manufacturer provided data and/or data obtained from LED calibration in the factory. The resultant value obtained from the look-up table, for each LED, is then utilized by the control system to determine an actual contribution of each LED or independently-driven LED group to the light source. Power supplied to each LED is then adjusted accordingly.

In another embodiment and referring to **FIG. 4**, the control system determines power adjustment requirements by cross indexing each provided summed LED intensity value with a ratio of the component intensity values in a look-up table that includes manufacturer

provided data and/or data obtained from LED calibration in the factory. The resultant value obtained from the look-up table, for each LED or independently-driven LED group, is then utilized by the control system to determine an actual contribution of each LED to the light source. Power supplied to each LED is then adjusted accordingly.

5 The above-described apparatus and method for sensing light emitted simultaneously from multiple light sources are example methods and implementations. These methods and implementations illustrate one possible approach for sensing light emitted simultaneously from multiple light sources. The actual implementation may vary from the method discussed. Moreover, various other improvements and modifications to this invention may occur to
10 those skilled in the art, and those improvements and modifications will fall within the scope of this invention as set forth in the claims below.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive.

CLAIMS:

1. A light source control system comprising:
 - at least one light source, each light source emitting a light signal at a discrete frequency and a reference signal at the discrete frequency;
 - a photodetector optically coupled to the light source, the photodetector designed to receive the light signal; and
 - at least one lock-in system coupled to the photodetector and each light source, each lock-in system receiving the light signal from the photodetector and receiving the reference signal from the light source;
 - wherein each lock-in system produces an intensity value of the light source based on the light signal and the reference signal.
2. The apparatus of claim 1 wherein each light source comprises:
 - a control unit; and
 - a colored light source designed to receive a drive signal from the control unit and produce the light signal based on the drive signal.
3. The apparatus of claim 2 wherein the control unit is designed to receive a clock signal and a power signal, produce the reference signal at the discrete frequency based on the clock signal, and produce the drive signal based on the reference signal and the power signal.
4. The apparatus of claim 1 wherein the photodetector comprises a single-junction photodiode.
5. The apparatus of claim 1 wherein the intensity value is the intensity of the light signal at the associated discrete frequency.

6. The apparatus of claim 1 wherein each lock-in system comprises:
a frequency multiplier; and
a filter, the filter coupled to the frequency multiplier;
wherein the intensity value is the product of the received light signal and the reference signal processed through the frequency multiplier, and filtered to remove non-dc portions.
7. The apparatus of claim 6 wherein the filter is a low-pass filter.
8. The apparatus of claim 1 wherein the photodetector comprises a multi-junction photodiode.
9. The apparatus of claim 8 wherein each junction of the multi-junction photodiode receives a portion of the light signal, the portion of the light signal received based on an associated spectra of the light signal.
10. The apparatus of claim 9 wherein the at least one lock-in system comprises a plurality of lock-in devices, each lock-in device coupled to the photodetector to receive a portion of the light signal.
11. The apparatus of claim 10 wherein each lock-in device comprises:
a frequency multiplier; and
a filter, the filter coupled to the frequency multiplier;
wherein a partial intensity value is produced from the product of the portion light signal received by the lock-in device and the reference signal processed through the frequency multiplier, and filtered to remove non-dc portions.
12. The apparatus of claim 11 wherein the intensity value is the sum of the partial intensity values.

13. The apparatus of claim 11 wherein the filter is a low-pass filter.
14. A method for sensing intensity of a light source:
emitting at least one light signal, each light signal emitted at a discrete frequency;
transmitting a reference signal associated with each of the light signals at the associated discrete frequency; and
producing an intensity value based on the light signal and the associated reference signal.
15. The method of claim 14 wherein emitting the light signal comprises:
receiving a clock signal;
receiving a power signal; and
producing the light signal based on the clock signal and the power signal.
16. The method of claim 14 wherein transmitting the at least one reference signal comprises:
receiving a clock signal; and
producing the reference signal based on the clock signal.
17. The method of claim 14 wherein producing the light signal comprises:
receiving the light signal into a lock-in system;
multiplying the light signal by the associated reference signal; and
filtering non-dc portions from the multiplied signal.
18. The method of claim 17 wherein receiving the light signal comprises:
collecting the light signal with a photodetector; and
passing the collected light signal to the lock-in system.

19. The method of claim 17 wherein receiving the light signal comprises:
collecting a first portion of the light signal with a first portion of the photodetector;
collecting a second portion of the light signal with a second portion of the photodetector;
passing the first portion of the light signal to a first lock-in device within the lock-in system; and
passing the second portion of the light signal to a second lock-in device within the lock-in system.
20. The method of claim 19 wherein producing the light signal further comprises:
summing the first portion of the filtered light signal and the second portion of the filtered light signal.
21. A system for sensing intensity of a light source:
means for emitting at least one light signal, each light signal emitted at a discrete frequency;
means for transmitting a reference signal associated with each of the light signals at the associated discrete frequency; and
means for producing an intensity value based on the light signal and the associated reference signal.

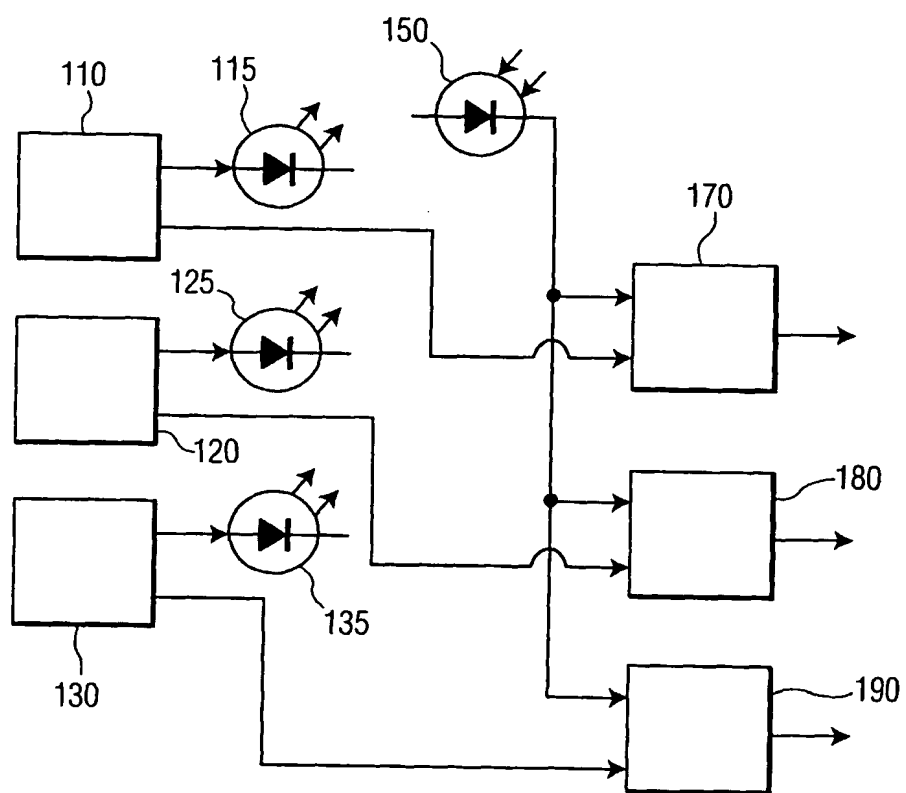


FIG. 1

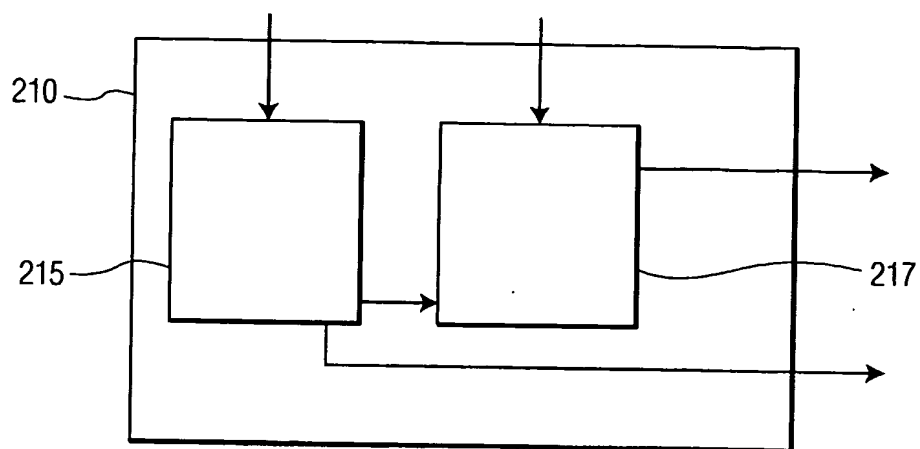


FIG. 2

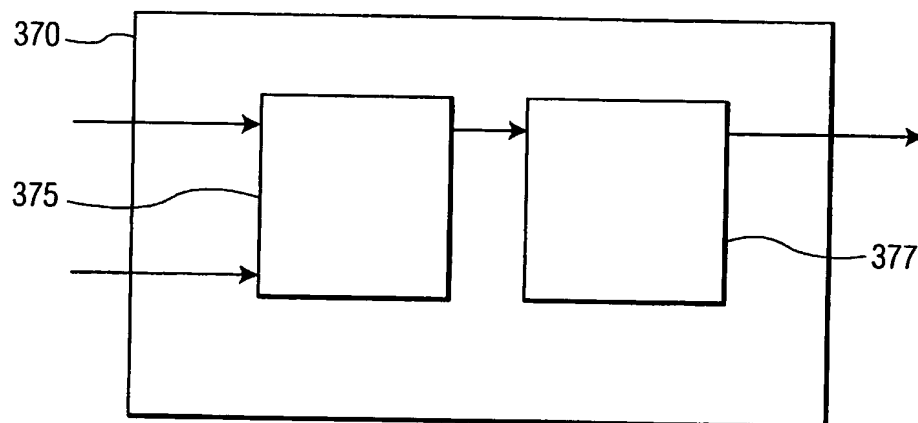


FIG. 3

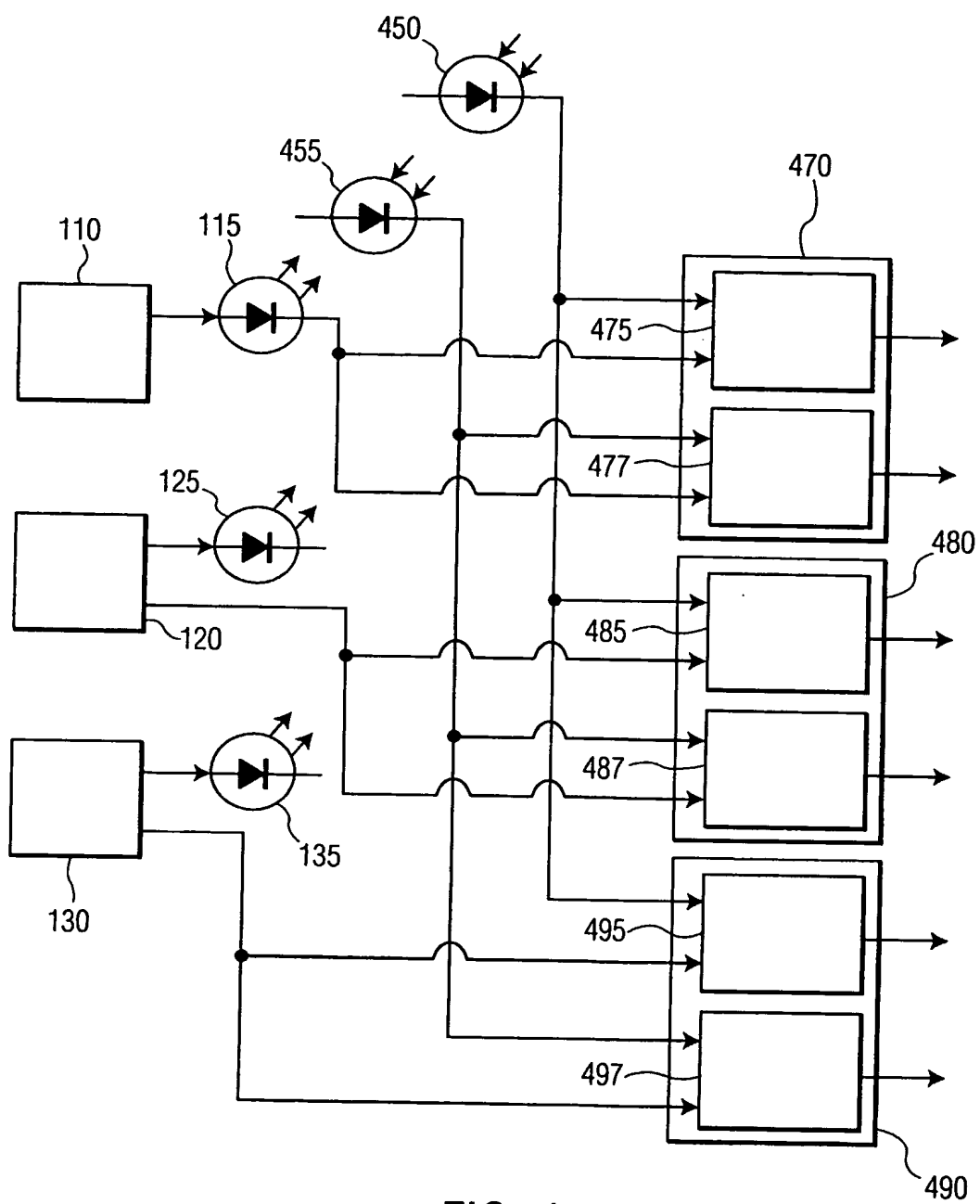


FIG. 4

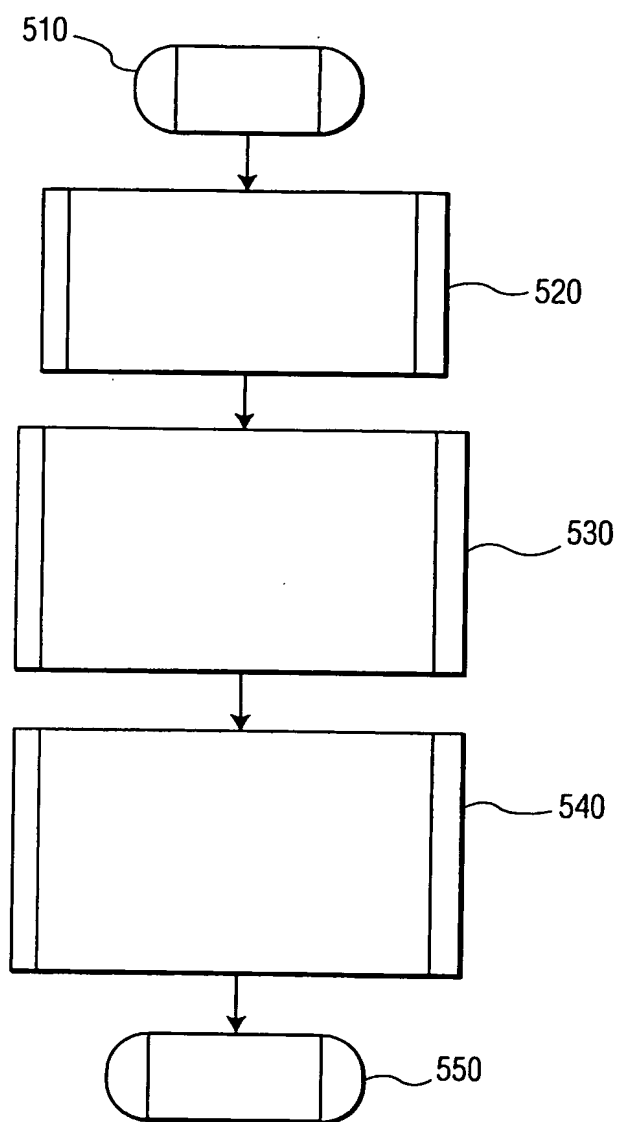
500

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/05983

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H05B33/08 G01R23/16 G06G7/19

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H05B G06G G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 055 251 A (MAJIMA MASAO ET AL) 25 April 2000 (2000-04-25) column 11, line 9 - column 13, line 21; figures 13-16	1-7, 14-18,21
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A	US 5 172 058 A (TASCA JEAN-PIERRE) 15 December 1992 (1992-12-15)	
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 March 2004

Date of mailing of the international search report

09.06.2004

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INTERNATIONAL SEARCH REPORT

Int'l Application No
PCT/JP 03/05983

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 328 686 A (FUCHS ABRAHAM M) 27 June 1967 (1967-06-27) -----	
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 03/05983**Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)**

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-7, 14-18, 21

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-7,14-18,21

A system for sensing intensity of a light source comprising:
emitting at least one light signal at a discrete frequency;
transmitting a reference signal associated with each of the
light signals at the associated discrete frequency; and
producing an intensity value based on the light signal and
the associated reference signal;
wherein the light source comprises:
a control unit; and
a coloured light source designed to receive a drive signal
from the control unit and producing the light signal based
on the drive signal.

2. claims: 8-13,19,20

A system for sensing intensity of a light source comprising:
emitting at least one light signal at a discrete frequency;
transmitting a reference signal associated with each of the
light signals at the associated discrete frequency; and
producing an intensity value based on the light signal and
the associated reference signal;
wherein a photodetector for sensing the light signal comprises
a multi-junction photodiode.

INTERNATIONAL SEARCH REPORT

Information on patent family members

In International Application No.

PCT/JP 03/05983

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